# NEUROPATHIC ULCERATION

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Perforating ulcers of the feet and chronic destructive ulceration of hands are among the most serious and stigmatizing complications of Hansen's disease (HD). If they are not prevented or controlled they result in gross crippling and incapacity. They also confirm in the patient's mind the latent suspicion that HD is inevitably a progressive destructive disease and that medical treatment is a failure. It is therefore vital to the control of the disease, as well as to the rehabilitation of the patient, that both physician and patient should understand the actual cause of this problem and the practical means of its control.

Although the activity of the disease and the presence of mycobacterial infiltration of the tissues may render the part somewhat more vulnerable to the mechanical forces that cause ulceration, and although denervated tissues are marginally less competent than normal tissues in controlling infection and in healing wounds, these factors are insignificant when compared to the dominant cause of ulceration and destruction of these limbs. This is the misuse of the limb permitted by the lack of pain sensation. Conversely, it is true to say that if the limbs are given special protection and care to compensate for the loss of pain sensation, then perforating ulcers need never occur, and the loss of digits can be completely prevented. Accidental wounds will heal almost as fast as similar wounds in normal tissue.

The whole problem is really one of mechanics, not of medicine. The biological responses of these denervated limbs are qualitatively similar to those of normal limbs. It is the permitted pattern of mechanical stress that is different. Non-HD patients suffering familial radicular neuropathies, diabetic neuropathy, and spina bifida with insensitive feet suffer exactly the same type of problem and can be protected in the same way.

Physicians often do not understand the way in which mechanical forces can harm the tissues. They tend to group all such wounds together and call them either "pressure sores," "trophic ulcers" or "mal perforans." I will now outline the mechanical causes of tissue breakdown and point out first that there are at least four totally different kinds of pathology, with four different types of force.

The methods of protection and prevention are also totally different. If we are to encourage our patients to have an active, meaningful life, and still try to prevent damage to their hands and feet, then we need to have a clear understanding of primary cause so that we may also have flexibility with regard to methods of prevention.

1. The first category is direct mechanical disruption, or tearing of the skin by mechanical force.

2. Second, very low pressure can cause damage if they are sustained continuously for many hours. The pathology of this type of damage is *ischemic gangrene.* The pressures are often of the order of 0.1 kg. per cm.

3. The third and commonest cause of breakdown of the skin is from moderate pressure 1.5 to 5 kgs per cm. repeated frequently many times a day, for day after day in succession. The pathology in such cases is traumatic inflammation followed by enzymatic autolysis of the tissues.

4. The fourth method occurs after one of the previous three. When the skin is broken, the tissues become infected. Continued walking causes pressure on the infected area, squeezing bacteria into fresh uninfected areas and resulting in the involvement of bone and tendon. It is this mechanical stress on an infected wound that is responsible for the most severe damage in insensitive limbs.

1) We shall consider these four one by one. It takes a pressure of something like 100 kgs per cm to cause direct crushing or tearing damage to the skin. This happens only when the whole weight of the body or the whole force of the hand impinges on an extremely small area, such as a nailpoint or a narrow edge of broken glass, or an extremely small metal handle, for example, the edge of a key. It is relatively easy for a thoughtful patient to protect himself from really severe local pressures. Any protective shoe will completely eliminate the danger of stepping on sharp objects. Protective gloves will often save the hands. Even without protective gloves patients should become alert to the danger of exerting a lot of force on a very small object. For example, we should enlarge the effective handle of all keys so that the edge does not press on a small area of skin.

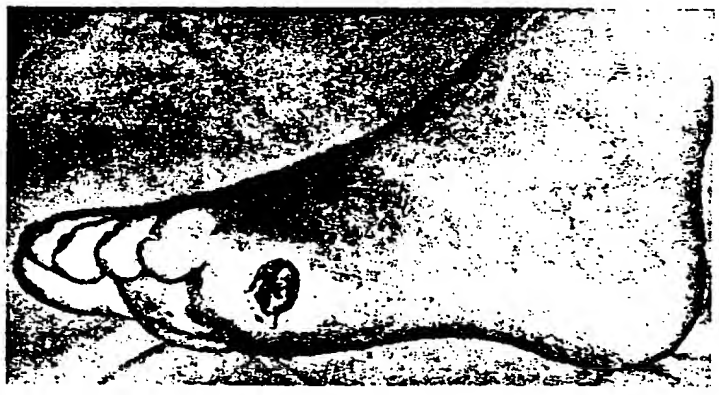

**Fig. 1. Ulcer and infection at the edge of a foot caused by a tight shoe worn all day.**

2) Low pressures that can cause ischemia (deficiency of blood supply) are only dangerous if they are maintained continuously for the greater part of the day. Figure 1 shows an ulcer on the edge of the foot caused by a new pair of shoes which were worn all day long after they were purchased. This type of pressure sore is relatively uncommon and is caused only by tight shoes, or tight



EXHIBIT "C"

bandages. This problem may be completely avoided by a careful fitting of shoes and by insisting that new shoes are only worn for two to three hours on the first days and are broken in gradually. Leather shoes are much better than plastic for insensitive feet because they will gradually adapt and accommodate to the shape of the foot.

In our experiments on pressure ulcers on pigs we were impressed with the fact that after several hours of pressure and before there was danger of actual ulceration the tissues were reddened and were thickened and swollen at the site of the pressure and that there was a patch of warmth which could be detected on a thermograph photograph, but could also be easily detected by the sensitive human hand. We suggest that everybody with insensitive feet should change their shoes in the middle of the day and should check their feet for patches of warmth and redness every night when they go to bed.

3) Far more common than direct mechanical injury and far more common than ischemic pressure sores is the type of plantar ulcer that can occur on insensitive feet. This is what has been called "mal perforans," "plantar ulcers" and "trophic ulcers" (Fig. 2). They have often been thought of as due to direct injury or as pressure sores, but the level of pressure which causes them is not nearly high enough to cause direct damage.

**Fig. 2 A typical plantar ulcer caused by the repetitive stress of walking.**

At Carville we began to understand the pathology of these ulcers when we tried to imitate them on the foot pads of rats. We fixed up an apparatus which would apply to the foot pad of anesthetized rats the actual amount of stress which would be experienced in the ordinary activity of vigorous walking. We found, for example, that a pressure of 1.5 kgs per cm applied repetitively 10,000 times per day resulted in some redness and swelling of the foot by the end of the day. After the second day there was increase in the temperature of the foot. Three days of repetitive stress caused more swelling and patches of inflammation. Histology of the foot pad showed enormous numbers of inflammatory cells. After eight days the grossly swollen foot had broken down and ulcerated. At no time did this rat have any stress higher than that which would be experienced in brisk walking or running. When similar foot pads were subjected to the same stress, but less frequently and with days of rest no breakdown occurred. A temperature evaluation showed at least an 8 degree centigrade increase in the temperature of the foot that had been exposed to repeated stress. I put my sensitive finger in the same apparatus. The stress was perfectly comfortable for the first few hundred repetitions. It then gradually became more uncomfortable and finally painful, before I withdrew my finger.

Our tests on normal feet have shown that normal individuals while running experience similar concentrations of pressure on one or two areas of the sole of their foot, but they soon change their gait so that the area is relieved of stress in response to the commencing pain.

Other parts of the foot are allowed to take the stress in turn. We are convinced that the major cause of breakdown of the foot of HD patients is simply that they do not change their gait, they do not limp, because they are not aware of the build-up of inflammatory stress in one or two areas of their foot.

We have studied the distribution of pressure under the foot of normal and of insensitive individuals. Here for example is a normal foot (Fig. 3) with pressure transducers attached and here is a tracing of five pressure points: the heel, three metatarsal heads, and the great toe. In this foot the highest pressures were at the end of the second metatarsal. We had this individual walk without change of pace across three different types of floor. The first step was on a floor of cement, the second was across a pad of leather, and the third a half inch thickness of microcellular sponge rubber. We see that on the hard surface there was wide contrast between the pressure under the different parts of the foot. The second metatarsal took pressures of about 5 kgs per cm. On the leather the contrasts were diminished and the high pressure point was little more than half as high as when it was on cement.

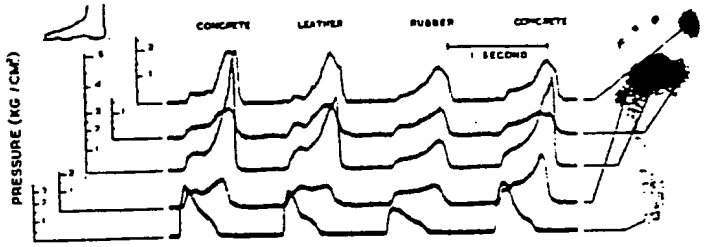


**Fig. 3. Pressure tracing of a man walking on a cement floor [1st step] a leather pad [2nd step] a micro cell rubber [3rd step]. Note how all the five points on the foot take about equal pressure when the foot is on the micro cell rubber.**

On the microcellular rubber all the pressures under the foot were very similar to each other and the highest pressures were low enough to be harmless over a period of some thousands of repetitions. This demonstrates one way of minimizing danger to the foot. If an extra-depth shoe is provided with a soft molded insole it may be possible to ensure that all of the foot will take approximately equal pressure. Under these circumstances only an extremely long walk or succession of walks is likely to produce enough build-up of inflammation to cause breakdown. For feet which have had previous ulcerations and which are shortened and have irregular bones we like to add the precaution of a rigid sole with a rocker under the middle of the shoe so that the foot tilts on a central pivot, rather than rising on the ends of the metatarsals or the end of the shoe. In this way pressures are markedly well equalized.

The most dangerous activities for the hand are when a single instrument is used repetitively over and over again.

A hammer or a screwdriver, used all day long, may well result in a localized blister or breakdown of tissue.

Hands that are somewhat already crippled may be limited in the way they can grasp tools and instruments. They may be confined to just one type of grasp, exposing just one piece of tissue to repeated stress and the same piece of tissue takes the stress no matter what implement is grasped. For this kind of patient it is very important that the tissues at risk should be protected, either with a glove, or by a specially molded tool handle; sometimes by an adhesive patch of moleskin or thin adhesive felt, or sponge rubber.

In both the hands and the feet, the surest sign of impending danger is an area of heat. Since it is fairly expensive to use temperature monitoring devices, we recommend that a family member, such as a spouse, be encouraged to use their sensitive hands to feel the hands and feet of their insensitive family member, and warn of danger when they feel a hot finger, or a hot part of the foot. At that stage a slight decrease of activity, or a change of shoe, or of a tool, may prevent tissue breakdown.

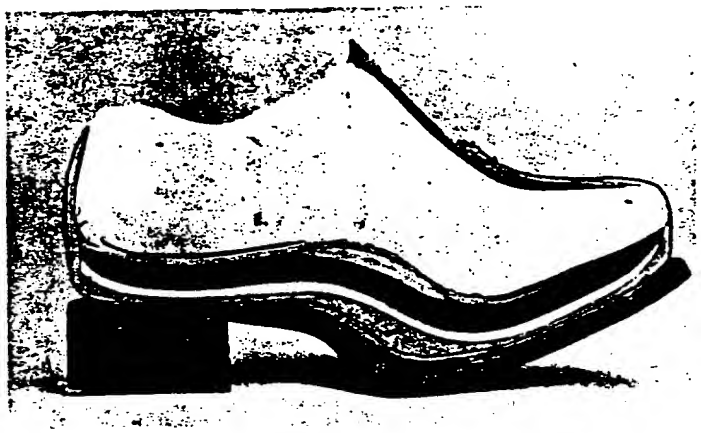

**Fig. 4. The structure of a rigid-soled rocker shoe.**

4) Finally, we must emphasize that the greatest danger of all is not mechanical stresses that result in the breakdown of skin, it is the continued use of an already wounded hand or foot, because the wound does not hurt. In an intact foot which is found to have a hot spot or redness or swelling, it is enough sometimes just to diminish the level of activity to allow the inflammation to subside. For an infected wound when the skin is already broken, we strongly recommend that no such half-measures should be adopted. The rule for a wounded or ulcerated foot is "no walking at all," and the rule for an infected or wounded finger is "keep it in a splint, keep it out of action."

We find that the best way to manage an acute perforating ulcer, or plantar ulcer, is to have the patient in bed and on antibiotics. The patient should not walk, even to the bathroom. As soon as the acute phase has settled down and there is no longer any fever, or profuse discharge, it is good to put the patient into a plaster cast, and allow him to walk with the carefully molded support of that rigid splint. Plantar ulcers heal very well with this program, so long as there is no deep sinus, or extension of the wound. In the case of deep extension, the opening of the wound to the surface should be widened until it is as wide as it is deep, then it may be lightly packed with petroleum jelly gauze, and immobilized in a plaster cast until it is healed.

**Fig. 5. Molded plaster cast with central support will protect the foot and allow it to heal.**

After an ulcer has healed in a plaster cast, or by rest in bed, there are often two further problems which make it very likely that the ulcer will recur. One is the presence of the scar, and the other is the presence of irregular projections of bone.

**The healed scar**

There are two types of force which occur on the sole of the foot, one is vertical force at right angles to the foot, which causes direct pressure on the tissues. The other is horizontal force, or shear stress, which is parallel to the surface of the foot and occurs in association with acceleration and deceleration. Of the two forces shear stress is more damaging than pressure. The scar by which an ulcer heals is often thinner than the normal tissue which it replaces, but it is reasonably well adapted to accepting pressure. Thus an ordinary soft or molded insole will usually allow a scar or healed ulcer to remain intact and healed.

When it comes to shear stress a scar behaves completely different from normal tissue around it. Normal skin is connected to the bones and ligaments by a rather loose web made of strands of collagen fibers woven around little cells of fat. When there is a horizontal thrust imposed on the foot and the skin is subjected to the forces of acceleration, or of deceleration, all of the rather loose fibers come under stretch and the skin is able to move over the bones to the extent of perhaps 1 cm backwards or forwards. In this way the forces that are applied to the skin are gradually transmitted to the skeleton, or vice versa, and no damage occurs.

However, when one small piece of skin has healed after being ulcerated it will often be attached to the bones by short dense fibers of a newly formed scar. These fibers are not loose, they are tight. They are not long, they are short. After several months they will become strong and perhaps will be somewhat stretched, but in the first month or two after the healing of the scar these short dense fibers are still weak and can easily be torn. Thus, the stage is set for disaster. Because the patient has no sensation, and because he sees that his ulcer has healed, he is ready immediately to start walking fast. When he starts to walk he thrusts the foot backwards to propel himself forward. When he wants to stop, his foot is thrust forward with the skin on the floor. In both cases there is severe shear stress between the skin and the skeleton. Since the scar is the only part of the skin which is not able to move over the bone the scar serves as an anchor and absorbs all the force of the shear stress, because its fibers are the only fibers

that will not allow the skin to move on the bone. Thus it concentrates stress and the tissues are torn. The wound is often reopened and forms a fresh ulcer.

I have emphasized the problem of shear stress in order to advise (a) that for the first month after an ulcer has healed patients should be advised to walk gently and take short steps, and never to run or jump, (b) the insole which they wear in their shoes should be of a type which allows the foot to slide a little on the surface of the insole. This would allow the thrust on the foot to be accepted on the back of the heel and by the sides of the shoe, and it will prevent shear stress on the sole. The foot does not slip easily on naked rubber; it slides quite well on a leather lining, or on a fabric like nylon. If the insole is not at all slippery then the patient should wear two pairs of sock, so that there might be some sliding between one sock and the other rather than between the sole of the foot and the shoe.

## IRREGULAR BONE

As a result of recurrent infections of the foot the metatarsal bones may be partly destroyed. Some will be prominent and long; others will be very short. This means that when the heel is lifted from the ground the weight of the body will rest on the long bones only and there will be localized points of very high pressure. These may cause secondary ulcerations. It is possible to accommodate these projecting bones by means of hollowed out areas in the sole of the shoe. However, since a person will have many different shoes for the remainder of his life, but only one pair of feet, it is often wise to perform minor surgery on such a foot and shorten some of the projecting bones so that they all touch the ground at the same time and present a wide surface to bear weight, rather than localized projections.

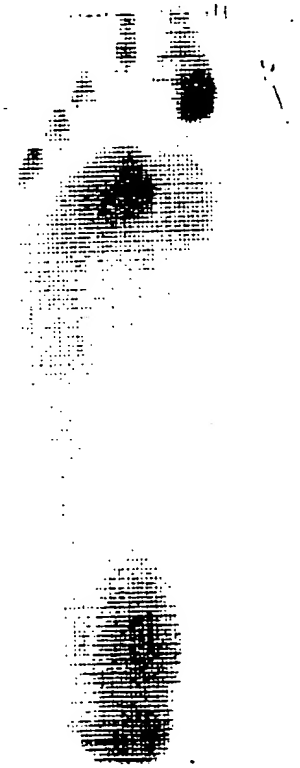

**Fig. 6. A Harris pressure footprint is of assistance in identifying points of high pressure. Molded insoles can help to equalize such pressures.**

Although the surgery is minor, its effect is very significant. No surgeon should lightly remove bone from a foot which already has a diminished surface for weight-bearing. Every time a foot is made smaller by the removal of bone the average pressure over the whole foot is increased, because the weight of the body remains the same. I rarely remove or shorten a bone only because it appears irregular on an X-ray. I take a pressure footprint on a Harris Footprint Mat and see whether there is actually high pressure under the end of the bone; also I like to feel the foot after it had been walking a while, to see whether there is a high temperature area around the pressure point. The absence of any sign of inflammation usually means that the patient is successfully managing his foot without surgical intervention.

There is no easy answer to neuropathic ulceration. It is a matter of education and observation and adjustment and occasional intervention. The short term rewards are not dramatic but they do allow a person to live his whole life with his own feet and to remain active, unrestricted by frequent wounds and dressings and free from the fear of amputation. ☆

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